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The representation of response effector and response location in episodic memory for newly acquired actions: Evidence from retrieval-induced forgetting

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RUNNING HEAD: Retrieval-induced forgetting for action sequences

AUTHOR NOTE:

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ABSTRACT

Information retrieval can cause forgetting for related but non-retrieved information. Such *retrieval-induced forgetting* (RIF) has been previously found for semantically and episodically related information. The current study used RIF to examine whether response effector and location are encoded explicitly in action memory. Participants learned unique touchscreen responses to ten novel objects. Correct actions to each object involved left-hand or right-hand pushing of one of four possible object buttons. After learning, participants practiced two of the ten object-specific sequences. Unpracticed actions could share hand only, button only, both hand and button, or neither hand nor button, with the practiced actions. Subsequent testing showed significant RIF (in retrieval accuracy and speed measures) for actions that shared hand only, button only, or both hand and button with the practiced action. The results have implications for understanding the representations mediating episodic action memory, and for the potential of RIF as a tool for elucidating feature-based representations in this and other domains.

Keywords: action memory, retrieval-induced forgetting, response location and response effector representation

1. INTRODUCTION

Throughout our lives we learn to master new motor skills, from tying our shoelaces to learning to play the piano to learning to drive. In the early stages of skill learning we may rely on episodic memories of performing the task. The more we practice a skill, however, the less reliant we become on explicit memories. Instead multiple episodes may be replaced by procedural memory, allowing us to perform the action with little conscious awareness (e.g., Fitts, 1964). What is represented in these episodes and how can this be investigated?

One potentially useful method for inferring the microstructure of episodic memory representations uses interference effects from the retrieval-practice paradigm to deduce what information was represented (e.g., Anderson, Bjork, & Bjork, 1994). In the original retrieval practice paradigm targeting semantic memory, participants studied categories of related items (e.g., Fruit –apple, banana, orange, strawberry; Bird– blackbird, robin, pheasant, finch). Participants then performed retrieval practice on half of the items from half of the categories (e.g., Fruit –ap___, Fruit – ba___), producing three item types which differed in retrieval status: practiced items from the practiced category (Rp+ items; Fruit– apple, banana); unpracticed items from the practiced category (Rp− items; Fruit – orange, strawberry); and unpracticed items from the unpracticed category (Nrp items; the Bird category). Memory for all three item types was finally tested in a memory retrieval test. Typically, two findings occur. First, as one might expect, practiced items (Rp+) are facilitated in comparison to unpracticed items from the unpracticed categories (Nrp) – the *retrieval practice effect*. Second, and more surprisingly, unpracticed items from the practiced category (Rp−) are impaired in comparison to the Nrp items (i.e., Rp−<Nrp) despite both being unpracticed – the *retrieval-induced forgetting effect* or *RIF*. RIF can occur not only for semantically related information, such as word lists (e.g., Anderson et al., 1994; Anderson & Spellman, 1995), but also for episodically related information, (e.g., Ciranni & Shimamura, 1999; Koutstaal, Schacter, Johnson, & Galluccio, 1999; Noreen & M.D. MacLeod, in press; Sharman, 2011).

1.2 Use of RIF to study the micro-structure of episodic action memory.

If RIF affects memory for actions, then it can be exploited in order to examine what is encoded in episodic action memory and could contribute empirically to discovering potential mechanisms underlying RIF. For example RIF could potentially reveal whether *action features* such as the response location (e.g., specific phone button) and response effector (e.g., hand) are explicitly represented in action memory. While Sharman (2010) has demonstrated that RIF can affect episodic memory for actions, use of the technique to reveal what is encoded in action memory has not been undertaken. Sharman showed that when an action is performed with a familiar object (e.g., Phone – lift), other actions associated with the same object (e.g., Phone – press key) are susceptible to RIF. While this finding suggests that the object is part of the action representation, it does not address whether RIF might be sensitive to what is encoded in episodic action memory – particularly what action features might be mediating behaviour.

Little is currently known regarding the representation of action features in *episodic memory for actions*. Much of the research on episodic action memory has been focused on the 'enactment effect' (see Roediger & Zaromb, 2010 for a review) whereby there is superior memory for action phrases (such as ‘pick-up the pen’) when they are followed by enactment of the phrases (with real or imaginary objects) during study as opposed to verbal learning alone (e.g., Cohen, 1981; Engelkamp & Krumnacker, 1980; Paris & Lindauer, 1976; Saltz & Donnerwerth-Nolan, 1981). It remains unclear whether action representations in episodic memory include information about response location, response effector, or both. For example, performing a simple action such as pressing key ‘b’ with the right-hand index finger involves at least two action features: the *response effector* (right hand or right index finger) and the *response location* (key ‘b’). If one or both of these features is represented in episodic action memory, then actions that contain one or both of the features could potentially show RIF.

There is both theoretical and empirical support for the explicit encoding of response location in action memory, while the question of whether response effector is encoded has received mixed support. A large number of studies using the Simon task (e.g., Heister, Schroeder-Heister, & Ehrenstein, 1990; Riggio, Gawryszewski, & Umiltá, 1986), object affordances (e.g., Phillips & Ward, 2002), imitation (e.g., Bekkering, Wohlschlager, & Gattis, 2000; Hamilton, Brindley, & Frith, 2007), visual habituation (e.g., Woodward, 1998), neurophysiological approaches (e.g., Alexander & Crutcher, 1990), and brain imaging methods (e.g., Grafton, Hazeltine, & Ivry, 1998; Hamilton & Grafton, 2006), have suggested that response location, but not response effector, mediates performance. Studies using motor sequence learning paradigms designed to examine implicit motor memory (e.g., Nissen & Büllemer, 1987), have similarly provided evidence that motor sequence learning is effector-independent (i.e., not sensitive to which hand learned the sequence), at least during the early stages of learning (e.g., Berner &

Hoffman, 2009a; Kovacs, Mühlbauer, & Shea, 2009; Park & Shea, 2003; Verwey & Clegg, 2005; Verwey & Wright, 2004). Findings from these studies suggest that response location (and the end goal of actions) are explicitly represented in episodic memory, but the response effector may not be (e.g., Keele & Curran, 1995; Deroost & Soetens, 2006; Willingham, Wells, Farrell, & Stemwedel, 2000; Witt & Willingham, 2006; see Abrahamse, Jiménez, Verwey, & Clegg, 2010 for review).

In contrast to negative conclusions regarding the representation of response effector in action memory, other empirical evidence has led to the conclusion that response effector can be explicitly encoded. Some object affordance investigations have shown that left- or right oriented objects such as a frying-pan, can automatically evoke responses from a compatible effector (e.g., Tucker & Ellis, 1998). Similarly, stimulus-response (e.g., Rieger, 2004) and response-effect (e.g., Hoffman, Lenhard, Sebald, & Pfister, 2009) compatibility phenomena have been shown to pertain to both the response location *and* the response effector. Interestingly, one of the critical pre-requisites for effector-dependent representations to be detected appears to be extensive practice in responding and interacting with stimuli (e.g., skilled typing: Jordan, 1995; Rieger, 2004; 2007; implicit sequence learning: Berner & Hoffman, 2009a; Verwey & Clegg, 2005; Verwey & Wright, 2004; implicit movement learning: Kovacs, Mühlbauer, & Shea, 2009).

In sum, previous studies have shown that stimulus-related actions are primarily mediated by spatial representations of response locations, while response effector representations appear to influence behaviour mainly after substantial amounts of practice or experience interacting with a stimulus or object. The application of RIF could potentially contribute to our knowledge by helping to determine whether response effector is represented in episodic action memory – even at an early stage of learning.

The current study examined whether RIF occurs for location and effector action features in episodic action memory. Encouragingly, RIF has been used to reveal feature-based representations in the past (e.g., Anderson & Spellman, 1995, Anderson et al., 2000 for verbal material; and e.g., Ciranni & Shimamura, 1999 for visuo-spatial material). If newly acquired object-related actions are represented in a feature-based format where both the response location and effector are represented in episodic memory, then RIF might occur for actions that share either one or both features with the practiced action.

Novel, vertically symmetrical objects were used and participants learned to interact with each of them by pressing a specific object button with a specific hand (Figure 1). The task examined explicit, as opposed to implicit, action memory. This was ensured by instructing participants to learn a set of simple actions to each of 10 novel objects, and subsequently asking them to re-produce those actions. Both the intentional learning instructions and the subsequent request to consciously access the learnt object-action sequence associations, violate the major criteria for implicit learning (see Abrahamse et al., 2010 for review). This allowed us to examine episodic, newly acquired, as opposed to well-practiced object-action associations and to disentangle the representations of response location (button) and response effector (hand), by ensuring that there were no pre-potent responses to any of the stimuli, which may have contaminated the results, neither at the level of the hand (e.g., a frying-pan oriented to the right might automatically evoke a right-hand response to righted-handed participant) nor at the level of the response location (e.g., the handle of the frying-pan may automatically evoke a response to its location).

Participants learned unique touchscreen responses to ten novel objects (Figure 1A and B). Correct actions to each object involved lifting either the left or the right hand from a response box, and using the same hand, pressing one of four possible action buttons on the object via a touchscreen. After learning, participants practiced two of the ten object-related action sequences. There were four types of unpracticed actions: those that shared neither hand nor button associated with the practiced action (Nrp baseline); those that shared hand only (Rp− Hand) or button only (Rp− Button) with the practiced action; and those that shared both hand and button (Rp− Both) with the practiced action. Retrieval accuracy and execution speed for the action was measured for all ten objects.

Assuming that RIF is sensitive to episodic action memory representations, there are at least three potential outcomes. First, if the action memory makes explicit only the response location (object button) but *not the response effector* (hand), as suggested by the majority of evidence on action memory, then significant RIF would occur for unpracticed actions that share response location but not response effector with the practiced actions. Second, if episodic action memory makes explicit both the response location (button) *and* the response effector then significant RIF would be observed for unpracticed actions that share either of the two features with the practiced action. Third, if the response location and response effector are represented as a unitary episodic representation of the action sequence as whole, then there should be significant RIF for actions that share both hand and button (Rp− Both), but not for actions that include either of the two features alone.

Apart from predictions regarding the representation of effector and response location in episodic action memory- the current design allows us to contrast inhibitory and non-inhibitory accounts of RIF, and in particular retrieval interference or blocking accounts. According to inhibitory accounts of RIF (e.g., Anderson & Spellman, 1995; see Storm & Levy, 2012 for a review), during retrieval practice Rp- items compete with the Rp+ items for retrieval, and in order to allow efficient retrieval of the Rp+ items the memory representation of the Rp- items is inhibited (e.g., Anderson, Bjork, & Bjork, 1994; Anderson & Spellman, 1995; M.D. MacLeod & Saunders, 2005; Saunders & M.D. MacLeod, 2006). Therefore, significant RIF is predicted in the current study for any of Rp- action sequences, on the basis that they all share features with the Rp+ action sequences, and are all likely to compete during retrieval of the Rp+ sequence.

Non-inhibitory accounts of RIF include the retrieval interference or blocking accounts (e.g., Williams & Zacks, 2001; C.M. MacLeod, Dodd, Sheard & Wilson, 2003) and strategy disruption accounts (e.g., Dodd, Castel, & Roberts, 2006). According to retrieval interference or blocking accounts, RIF occurs because interference builds up along the retrieval route between the retrieval practice cue and the Rp+ items, blocking access to the Rp– items. Therefore, although significant RIF is predicted for Rp-Hand and Rp-Button actions, critically significant facilitation is predicted for the Rp-Both action sequences. That is because, according to blocking accounts, Rp+ and Rp-Both actions are identical, and memory retrieval of the latter can only benefit from retrieval of the former during the final test phase.

2. METHOD

2.1. Participants

Sixty-five participants (54 females) recruited from Swansea University participated in exchange for course credit or £5. All participants were naïve to purpose of the experiment.

2.2 Materials

The experiment was administered via a custom-written E-prime (version 2.0) program, on a 15 inch Mitsubishi NEC MultiSync high resolution LCD touchscreen monitor 50 cm away from the participant.

Ten grayscale object stimuli (see Figure 1A) appeared against a white background. Each object filled an 18 x 14 centimeter area. Each object had four parts corresponding to top, bottom, left and right with an action-button appearing on each part, and was associated with a specific hand and button action sequence during learning. There were eight possible hand-button combinations. Objects were not always associated with the same action, but instead different participants learned different actions for the ten objects. Therefore, all objects were associated with all of the actions across different participants. As all objects were novel with no pre-existing action associations, it was not important which action corresponded to which object. However, it was important that all eight possible actions served as Rp+ actions and as Rp– actions across different participants in order to avoid any unlikely but possible serendipitous item-based effects.

For each of the ten objects the object-action combinations, for a subset of participants, were determined as follows. First, two of the actions were selected to be Rp+ actions, with the constraint that both used the same hand, e.g., in Figure 1 the Rp+

items were the Right hand– Top button action and the Right hand –Right button action associated, in this case, with Objects 1 and 6 respectively. It was necessary that both Rp+ actions used the same hand, in order to avoid contamination of the Rp– Neither condition, where actions shared neither hand nor button. Among the remaining eight objects, two were associated with exactly the same action as the two objects selected to be the Rp+ items, thus creating the Rp– Both condition (e.g. in Figure 1, Objects 1 and 2 had exactly the same associated action, and this was also true for Objects 6 and 7). Among the remaining six objects two were associated with an action that used the same hand as the Rp+ items, two were associated with an action that required pressing the same object button as the Rp+ items, and two had an action associated with them that shared neither hand nor button with the Rp+ items. Apart from the Rp+ and Rp– Both actions, which were identical, there were no other repetitions of actions among the remaining objects, and they all had unique actions.

2.3 Design

The experiment was based on a within-subjects design manipulating the Action type variable (Figure 1B). Action type had five levels: (a) Rp+ actions: action sequences that were practiced during the retrieval practice phase; (b) Rp− Both actions: same hand and button action as the Rp+ items but not practiced; (c) Rp− Hand actions: unpracticed actions that shared hand (but not response button) with the practiced items; (d) Rp− Button actions: unpracticed objects that shared response button with the practiced motor sequence (but not hand); (e) Nrp actions: unpracticed actions that shared neither hand nor button with the practiced objects. The dependent measures were accuracy and response times.

(A)

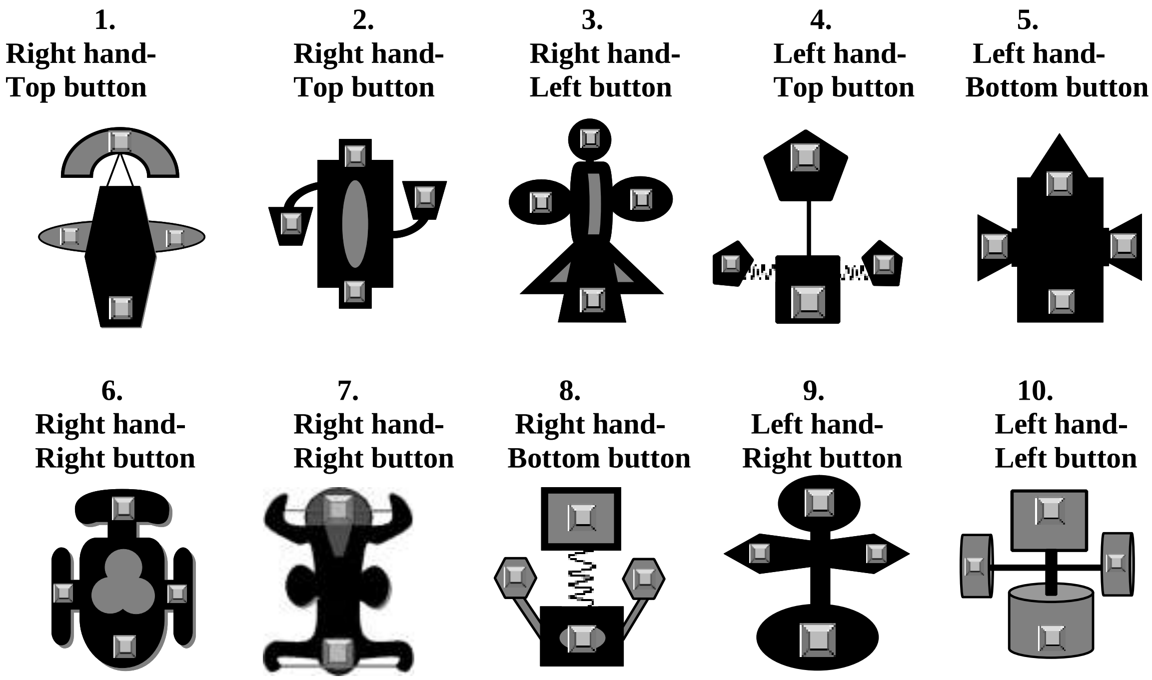

Figure 1: (A) The ten objects used in the current experiment. Each object was associated with a specific hand-button action, and such associations were different for different participants. Here only one of the possible object-action associations is shown. For this group of object-action associations, actions for objects 1 and 6 were selected for retrieval-practice, and the actions for the remaining objects were selected accordingly (see text for details).

(B)

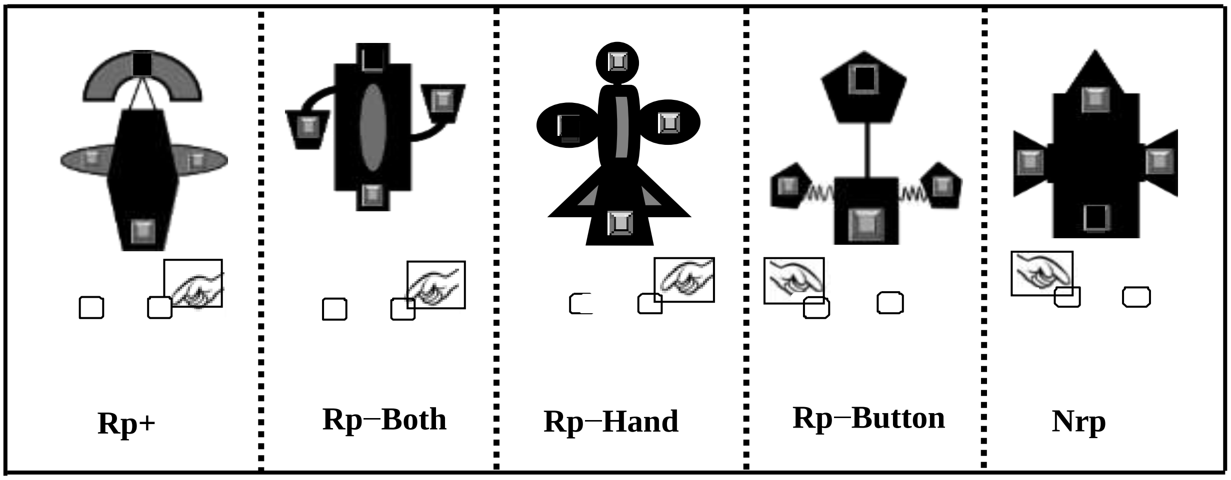

Figure 1: (B) Illustration of the different conditions shown for only half of the objects. The hatched square illustrates which object button required pressing and was not visible during the experiment. The outline square around the hand indicates the hand required to respond with. The conditions illustrated from left to right are Rp+: actions that were practiced during the retrieval practice phase; Rp−Both: same hand and button action as the Rp+ actions but not practiced during retrieval practice; Rp−Hand: unpracticed actions that shared hand (but not response button) with the practiced items. Rp−Button: unpracticed objects that shared response button with the practiced motor sequence (but not hand); and Nrp: unpracticed actions that shared neither hand nor button with the practiced objects.

2.4 Procedure

There were four phases in the experiment: two study phases, a retrieval-practice phase, and a test phase. In the first study phase, participants learned the correct hand and button response combinations for each of the ten objects. Three repetitions of all ten objects were presented one object at a time in a randomly intermixed order with the constraint that no object would appear twice in a row. Printed underneath each object was the hand to respond with and the touchscreen button to press (e.g., left hand – bottom button). Participants started each trial resting their left and right index fingers respectively on the left and right buttons of the button box. When the object appeared, participants had to press the button-box button with the hand they were to respond with, then lift that hand and press the appropriate button on the touchscreen object with the thumb, resulting in a grip-like hand posture. Thus, participants practiced both the correct hand and correct button for each object.

The second study phase was almost identical to the first, although objects appeared only once and without instructions. Participants were given auditory feedback on incorrect responses, and had to repeat the entire phase until they performed at least 70% of the trials correctly.

After the study phases, in the retrieval-practice phase, participants practiced the Rp+ actions. There were twelve possible retrieval –practice groups, where each of eight possible actions, was paired with another one which shared the same hand yielding six groups where retrieval–practice was done with the left hand, and six groups for whom retrieval–practice was done with the right hand. All the retrieval-practice groups are shown in Appendix 1, where the Rp+ and all the Rp –actions are shown for each group separately. Following a two-minute verbal word generation distractor task participants repeated the cycle of retrieval-practice and distractor task two more times, yielding a total of 9 retrieval practices for each of the two objects.

After retrieval-practice, participants completed a verbal name generation task for five minutes then began the test phase where they were asked to perform the correct action sequence once for each of the ten object stimuli. Object stimuli were presented in random order. This ensured that there would be no systematic presentation of Rp+ actions first, which may potentially interfere with subsequent Rp- or Nrp actions thereby producing RIF. No corrective feedback was issued in this phase.

3. RESULTS

Study phase data: A mean of 75 trials was required to reach criterion during the second study phase, where participants learned to perform the correct action to each of the ten objects, without the text prompt but with corrective feedback. Twenty-one participants completed this phase in a single study session (30 trials), 23 in two study sessions (60 trials), 18 in three study sessions (90 trials), and 4 participants in four study sessions (120 trials). Simple bivariate correlations revealed no significant correlations ($p>.05$ in all cases) between number of study trials and mean accuracy or mean RT in any of the four unpracticed conditions (Nrp, Rp-Both, Rp-Hand, Rp-Button).

3.1 Retrieval data: Accuracy scores were calculated separately for all action types (Rp+, Rp−Both, Rp−Hand, Rp−Button, and Nrp). Cell means for the accuracy data appear in Table 1. Each cell mean is based on the mean of two trials, therefore the possible cell means were 0, 0.5, and 1.0[1]. Separate non-parametric analyses were carried out to determine the facilitatory and RIF effect on accuracy scores.

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[1] Parametric paired-samples t-tests were also carried out, which showed the same pattern of results as the parametric analyses of accuracy scores. All paired-samples t-tests revealed significant differences between the Nrp baseline and the Rp+ actions and between the Nrp baseline and the three Rp– conditions (all *ts* (64)> .2, all *ps*<.04).

3.1.1 Facilitation: A pairwise Wilcoxon signed-ranks test revealed significantly higher accuracy for practiced actions compared to unpracticed Nrp actions, Z (65) = 2.54, p=.01.

3.1.2 Retrieval-induced forgetting: To examine whether retrieval practice impaired retrieval of unpracticed actions at test, accuracy scores for the four unpracticed conditions (Rp−Both, Rp−Hand, Rp−Button, Nrp) were entered into a Friedman non-parametric test for multiple-dependent groups by ranks, which was significant, χ^2 (3, N=65) = 15.67, *p*=.001. Pairwise Wilcoxon signed-ranks tests showed that RIF was significant for all Rp− actions: Rp−Both versus Nrp, Z (65)=2.18, *p*=.03; Rp−Hand versus Nrp, *Z* (65 =2.88, *p*=.004; and Rp−Button versus Nrp, *Z* (64)=3.74, *p*=.0001. There were no differences between the three Rp− conditions (all *Z*s < 1.1, *ns*).

Table 1: Mean proportion of retrieval performance (standard deviations in parentheses) for each type of action.

Rp+	Rp−Both	Rp−Hand	Rp−Button	Nrp
.86 (.29)	.55 (.39)	.51 (.39)	.48 (.33)	.71 (.35)

Table 2: Mean response times in milliseconds (standard deviations in parentheses) to perform the action.

Rp+	Rp−Both	Rp−Hand	Rp−Button	Nrp
1293.96 (680.66)	1879.53 (649.05)	1898.74 (670.63)	1925.33 (829.50)	1611.15 (660.87)

3.2 Response time data: Response time cell means appear in Table 2. All response times were included in the analysis with no exclusion of outliers. Two separate analyses were carried-out, one to determine facilitation and the other RIF. The response time data mirrored the pattern of RIF observed in the accuracy data.

3.2.1 Facilitation: A paired-sample t-test confirmed that Rp+ actions were performed faster than Nrp actions, t (64)=2.93, p=.004.

3.2.2 Retrieval-induced forgetting: A one-way repeated measures ANOVA revealed a significant main effect of Action type (Rp− Both, Rp− Hand, Rp− Button, Nrp) on response time, F (3, 192) = 3.78, p=.01. RIF was significant for all Rp− actions: Rp− Both versus Nrp, t (64) = 2.24, p=.02; Rp− Hand versus Nrp, t (64)=2.67, p=.009; Rp− Button versus Nrp, t (64)=2.95, p=.004. As with the retrieval data, there were no differences between the three Rp− conditions (all ts < 1, *ns*).

4. GENERAL DISCUSSION

The current study employed the retrieval-practice paradigm to examine the micro-structure of episodic action memory. The design of the study was poised to examine the following questions: Is there a micro-structure in episodic memory, where actions features – response location and response effector – are explicitly represented, and is RIF sensitive to it? Is both response location and response effector explicitly represented features in episodic action memory? The following main findings emerged. First, as may be expected practiced actions were retrieved faster and more accurately than unpracticed actions. Second, there was significant RIF for actions that shared hand only, button only, and both hand and button, while there was no difference between them. The findings show that there is a microstructure in episodic action memory, where response location and response effector are explicitly represented, and RIF was sensitive to it.

4.1 Methodological Issues

The design and procedure in the current study make a novel and significant departure from the prototypical retrieval practice procedure. In the typical paradigm where category-exemplar pairs are used, e.g., FRUIT-banana, FRUIT-orange, any presumed response competition during retrieval of FRUIT-banana, potentially leads to RIF for unpracticed exemplars, e.g., FRUIT- orange. In this example, the category cue is explicit, in the sense that it is explicitly linked to each item, and the experimenter explicitly uses it to probe the participant's memory of those items.

The departure of the current design from this typical procedure lies in the fact that each exemplar (action sequence) was associated with a unique cue (object). So, how did response competition arise, in a design where the explicit category cue (e.g., the object), was unique to each action? Although each action sequence was uniquely cued by a different object, different features – response effector and response location – were implicitly shared between different actions. Therefore, any competition between actions during retrieval practice of a specific action (e.g., Object 1-> right hand-top button) would arise from the similarity of the practiced action to other actions that share either some features (e.g., right hand *or* top button), or all of its features (right hand *and* top button). In other words, response competition in the current study arose from sharing implicit categories, which were formed after many repetitions of the sequences.

4.2 Implications for the microstructure of episodic action memory

The finding that the episodic memory for response location is susceptible to RIF provides converging evidence for the special status that response locations, and action goals in general, enjoy in implicit motor memory (e.g., Willingham et al., 2000; Deroost & Soetens, 2006; Witt & Willingham, 2006) and in cognition in general (e.g., Alexander & Crutcher, 1990; Bekkering et al., 2000; Grafton et al., 1998; Heister et al., 1990; Hamilton & Grafton, 2006; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Phillips & Ward, 2002; Riggio et al., 1986; Woodward, 1998). What is particularly interesting in the current study is that the correct response location for each object was entirely arbitrary as the objects were symmetrical, and being novel had no prior action associations. Although object-button associations were acquired within a single, short experimental episode, they were nevertheless successfully encoded in episodic memory and influenced retrieval. The current finding suggests that response location can influence behaviour even if it is spatially arbitrary and newly acquired.

A more important finding relates to the action effector, given the mixed evidence regarding its encoding in action memory. There was significant RIF for unpracticed actions that shared the same effector (hand) with the practiced actions, irrespective of whether response location was shared or not. This finding demonstrates that the response effector is a represented feature in episodic action memory. This is the first report of effector-dependent action representations for newly acquired object-action associations, following a limited amount of learning (a total of 4 study trials per object-action association). Most previous demonstrations of effector-dependant representations were evoked within highly skilled tasks, such as typing (e.g., Jordan, 1995; Rieger, 2004, 2007), responding to familiar objects with which one has extensive experience of previous interactions (e.g., Tucker & Ellis, 1998), or in implicit sequence learning tasks following extensive practice of over 1000 trials (e.g., Berner & Hoffmann, 2009a; Kovacs et al., 2009; Park & Shea, 2003; Verwey & Clegg, 2005; Verwey & Wright, 2004; but see Berner & Hoffman, 2009b for effector-dependent effects following a minimum of 120 trials). The current finding of effector-dependent representations is compatible with the fact that learning new manual skills, such typing or playing an instrument, involves often explicitly learning a series of perception-action associations to be held in memory and later retrieved given the appropriate cue (object or task). Initially, we tend to rely on episodic/declarative memories of the object-action associations, before those give way to procedural memories. Our study phase represents the early stage of action learning and skill acquisition, and shows that at this stage both the response location and response effector are encoded and guide behaviour.

The finding that both response location and effector were susceptible to RIF indicates that the two action features are represented in episodic action memory, and actions that share either feature can potentially influence retrieval of other actions that have the same feature (e.g., other actions sharing the same response location or the same responding hand, or both). Interestingly, sharing both action features (Rp– Both) did not lead to greater RIF than sharing only one of the two features (Rp– Hand or Rp– Button conditions). One possibility is that the two features are represented separately in a distributed feature-based representation (e.g., McClelland & Rumelhart, 1985), or they are part of an integrated representation where each feature is accessed independently of the other (e.g., Hommel et al., 2001). Distinguishing between the two alternatives is beyond the scope of the current study. However, regardless of which alternative turns out to be true, our findings show that both action features are explicitly represented in action memory and influence retrieval of actions.

The finding that selective retrieval of an action was detrimental to the memory of the exact same action retrieved using a different cue (e.g., a different object; Rp− Both condition), suggests that memory for actions is not inextricably linked to the objects they are associated with, and the representations of objects and their associated actions are not necessarily bound in a single, non-differentiated representation. Previous work on RIF for actions (e.g., Koutstaal et al., 1999; Sharman, 2011) has shown that actions learned in the same experimental episode (e.g., Koutstaal et al., 1999) or actions associated with the same object (e.g., Sharman, 2011) are susceptible to temporary forgetting following retrieval of some of the actions in that episode. Our findings complement this work by showing that an object can independently cue actions that share only some of the features of the practiced action.

4.3 Implications for the RIF literature

The current study reveals the potential of RIF to be used as a tool to examine feature-based representations. As such, the current results extend previous work with semantic (e.g., Anderson, McCulloch, & Green, 2001; Anderson & Spellman, 2009) and episodic (e.g., Ciranni & Shimamura, 1999; Noreen & M.D. MacLeod, in press) material, to action representations. Using RIF, our study has extended the investigation of episodic action memory from understanding the influence of enactment (or self-performance) on successful retrieval of studied actions, to understanding the micro-structure of actions themselves. For instance, in addition to response location and response effectors, RIF may be used to examine the representation of other action features, such as movement direction (e.g., Richard, Clegg, & Seger, 2009), and inform us whether such a feature is encoded in the representation mediating action memory[2].

The current study was not designed to specifically contrast the predictions of inhibitory and non-inhibitory accounts of RIF, as there was no manipulation of item taxonomic frequency (e.g., Anderson et al., 1994; but see Levy, McVeigh, Marful, & Anderson, 2007) or use of independent cues at final test (e.g., Anderson & Spellman, 1995; M.D. MacLeod & Saunders, 2005; Saunders & MacLeod, 2006; Veling & van Knippenberg, 2004; see also Camp, Pecher, Schmidt, & Zeelenberg, 2009 and Huddleston & Anderson, 2012, for a recent discussion), both of which have been used to distinguish between the two accounts. Nevertheless, the results have the potential to distinguish between inhibitory and non-inhibitory, especially blocking accounts of RIF. Blocking accounts of RIF might predict that following strengthening of particular object-action sequence (e.g., Left Hand - Top Button) during retrieval practice, during the final test phase participants may have attempted to re-initiate the practiced sequence, leading to delays and reduced accuracy for unpracticed actions. The finding that RIF (and not facilitation) was observed for Rp– Both sequences, suggests that blocking or re-programming of responses cannot account fully for the observed pattern of RIF. [3]

Finally, RIF is sensitive to newly acquired actions to novel objects (as opposed to only actions related with familiar objects; Sharman, 2011). One question for future research is whether such interference, as measured by RIF, remains for highly practiced

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[2] We thank Reviewer 1 for suggesting this possibility.
[3] We thank Reviewer 1 for bringing our attention to this aspect of our data and its implications.

action sequences deeply encoded in procedural memory. Previous research has indicated that action memory is less prone to interference with practice as the motor memory consolidates (e.g., Krakauer & Shadmehr, 2006), suggesting that highly practiced actions may be less susceptible to retrieval competition. Another, related question is whether following more extensive practice – a few hundred trials –the representations mediating our task, become effector independent, yielding significant RIF only for unpracticed actions that share the same response location as the practiced actions. Such an observation, could potentially demonstrate that ostensibly different memory systems can be governed by similar principles.

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